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ABSTRACT

Language acquisition is a quantifiable system with the sum total of verbal inputs and outputs increasing with the age of the subject. Increases in vocabulary are positively accelerated during developmental years and become negatively accelerated or zero during adult years. Thus, older people have available a larger active and passive vocabulary. To check the validity of the Bousfield and Sedgewick equations which predict vocabulary acquisition, a test was designed which required subjects of different ages to write all the words that occurred to them in a given interval of time. Contrary to expectations, older subjects did not show greater fluency--a finding which may reflect response time more than memory. Future research should focus on the factors that prevent individuals from making the most efficient use of stored information. The appendixes include an explanation of statistical methods and graphic summaries of test results. (EMH)

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The University of Michigan

Center for Human Growth and Development

Development of Language:

Suggestions for a Verbal Fallout Model

by

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NATIONAL INSTITUTE OF EDUCATION

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Development of Language:
Suggestions for a Verbal Fallout Model*

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Most spatial conditions can be reliably reproduced and measured, but changing temporal conditions--strictly speaking--can not. Until rather complex periodic processes had been identified and recording techniques developed it was impossible to deal with time except on a primitive psychological basis. Moreover, we do not sense the passage of time directly but rely on the changes in stimulation which accompany it. Thus, time perception is intimately linked with memorization. Since memory is never perfect, neither is time perception. If, indeed, we were able to retain every input received during a certain interval, our time perception could be perfect. In this case there would be no psychological gaps or "empty spaces" that could distort the time estimation; the intervening period between two instances of time would be solidly filled with psychological events that could be completely enumerated for time estimates.

Because of the difficulties described, it is not surprising that physicists devoted much attention to provide a theoretical foundation for the time dimension and its measurement. These attempts have led to a reduction of the time variable and to a substitution of time measurements by enumerative procedures of spatial conditions. The analysis of radioactive decay or of irradiative accumulation are characteristic examples of such attempts. Both processes (as well as perfect memory, mentioned above) represent enumerative processes. In order to explicate these attempts some statements about the measurement of time in physics will be made. (See also Maria Reichenbach and Ruth A. Mathern, 1959, and Strehler, 1962.)

Measurement of Time in Physics: Let us imagine that a film camera has been mounted above a billiard table across which a ball is rolling. If we obtain a film strip, cut it into single pictures, and randomize them, we will be able to reconstruct the order of the pictures but we cannot state for certain from which side the ball came. All that we can

reconstruct are the sequential properties but not the direction of the sequence.

Next, let us assume that a bar is placed across the billiard table and that one half contains a greater number of randomly moving balls than the other. After the bar is removed, more balls will change from the first into the second half. Ultimately they will be about eually distributed over the whole table. If we had taken pictures again, we would not only be able to reconstruct the sequences of moves, but could also ascertain the direction of the sequences. The state in which the two sets of billiard balls are still separated is less likely than the state in which they are mixed. The separate states can be reconstructed only through the intervention of some external (ordering) forces. During the normal course of events, the separate states will merge into a mixed one but not vice versa.

Our procedure allows the reconstruction of sequences as well as of their directions, but in order to do this we still relied on a periodic system, namely the film camera with its constant speed of exposures. The periodicity of the camera is not a crucial condition for the desription of physical systems, however. Although for all practical purposes we prefer a periodic and, in particular, a linear time concept, we might well imagine a film camera which takes pictures at irregular time intervals. In spite of this, we should be able to reconstruct sequences and their directions with a reasonable degree of accuracy.

Of greater importance, our procedure reduces indeed the measurement of time to an enumeration of spatially ordered events: First, we determined the sequence of these events by alligning them in a systematic manner. Then, we estimated the direction by separating the less probable from the more probable states. If we next want to derive measurements, we chop off equal numbers of observations from the less likely end of the ordered sequence assuming that under non-linear conditions, long and short distances between adjacent events will be randomly distributed.

Measurement of Time in Psychology: Almost exclusively, physical time measures have been applied in psychological research. In perceptual studies, for instance, the time for the identification of stimuli is taken in physical units. In studies of learning, the time for the acquisition of items as well as for the forgetting are measured in physical

terms. Noteworthy exceptions exist, however, for instance when the intervening periods are specified psychologically by the number of intervening lists or the amount of activity.

In developmental studies the age of Ss has been specified in physical units of chronological time. Quasi-psychological time-scales have also been applied for which the mental age scale of IQ tests is the most outstanding example. Interestingly enough, Ss do not necessarily progress equally on both scales, the chronological and mental age scales, but might reveal periods of retardation or acceleration in their intellectual growth. Similarly, intervening tasks in learning studies have different effects, depending on whether the material was interspersed early or late during learning.

Our examples have pointed to the usefulness of independent time measures for psychological research. Attempts to derive psychological time scales either dealt with the relatively short time periods of experimental studies, or with the measurement of age in developmental investigations. Most psychological studies of the short-term time variable have been restricted to subjective estimates of physical time periods (see Wallace and Rabin, 1960). The primary objective instigating the development of long-term psychological time scales has been to derive more meaningful interpretations of behavior changes than chronological age would allow us to do. Most of these scales have been selected for specific biological or psychological reasons and only a few have furthered our theoretical notions about growth and aging. Since the discussion of such theoretical notions will be the main purpose of our presentation, some statements on developmental theories need to be made.

Theories of Development: In spite of its impressive history, developmental psychology has not provided a clear answer to the question of why organisms grow and age. Some have tried to obviate the problem by declaring that time itself may serve explanatory functions and that, for instance, four-year-olds have a certain height because they are four years old. Others have been satisfied by the common attempts to reduce psychological development to changes in non-psychological conditions, particularly biological factors, and to substitute phenotypical by genotypical descriptions. Such an interpretation is implied, for example, when we explain growth in size by changes in the endocrine system.

For many purposes such explanations will be fruitful. But it merely removes the problem into another area of study, where the same question arises again and no satisfying answer is provided as to why organisms age.

In a more abstract form reductionism is implied when the time or age dimension itself is substituted by non-temporal factors. This possibility is inherent in all attempts to derive psychological or biological age scales independently from chronological age, for instance, by evaluating the potassium concentration, the calcification of certain organs, or merely the number of items solved on a mental age scale. If the evaluation of psychological or biological age is well substantiated theoretically, powerful explanations of growth and aging can be derived. For clarification of this point, let us consider two biological theories of development (for a comprehensive discussion see Strehler, 1962, and Curtis, 1963).

The first theory may be called Waste Theory. Basic metabolic processes of the cells lead to the production of waste products, such as lipofuscin, which cannot be completely removed and accumulate over the years until they reach a critical level and produce a slow or sudden decrease in functioning. This theory leads to the important notion that life itself implies growth and aging, namely via the accumulation of metabolic waste. The "waste theory" may be called an intrinsic theory of development: The biological age is determined by the amount of waste accumulated by and within the organism.

The second theory has been called the Mutation Theory and is concerned with the instability of the chromosomes in somatic and gonadic cells. Mutations--which are generally regarded as deleterious for the organism--occur at random. The older a person is, the greater the number of mutations that have occurred and the more likely it is that structural and functional defects will result.

Since the mutation rate depends on the amount of irradiation to which an organism has been subjected, some theorists regard the amount of radioactive fallout as a major determinant of changes during development and aging. This formulation is of importance not only because it suggests ways to manipulate developmental processes in the laboratory, but also because the determinant of age has become an extrinsic, non-biological entity. Again, the amount of irradiation received (fallout) may be used to redefine the time or

age scale. Thus, we may rid ourselves in another manner of chronological time as a primary dimension and at the same moment develop a deterministic interpretation of growth and aging.

SUGGESTIONS FOR A VERBAL FALLOUT MODEL OF LANGUAGE DEVELOPMENT

Contrary to what some experimentalists like to make us think, language does not consist of short responses in single situations but--as Anderson has put it--individuals are virtually "bathed in linquistic stimulation" (1949). A five-year-old may speak 12,000 words per day and will receive even larger quantities of spoken language. As a first question, we have to ask whether the amount of verbal activity on one hand, and of "verbal fallout" on the other, is about constant throughout life.

In spite of its practical importance, few reliable studies on age differences in the amount of communication are available. Figure 1 shows the results of a sample survey on the amount of time spent daily in reading. Even though we might question whether the type of material listed represents adequately the total written input, let us, for simplicity, accept the results as they are presented and, subsequently, let us agree that the amount of written input is about constant for the adult years. Accordingly, the total number of messages received will increase linearly with age.

Insert Figure 1 about here

Messages differ in quality or information value, and, on the average, the information value decreases with the length of messages. What is the precise relationship between these two variables?

Fortunately, researchers in literary statistics have dealt extensively with this problem and have suggested a number of mathematical models. Thus, Carroll (1938) analyzed the relationship between the number of different words (types) and the total number of words (tokens) in James Joyce's Ulysses. Plotting the first occurrence of any word in an accumulative manner against text length, he derived a negatively accelerated trend shown in Figure 2. For our present purpose it is conceptually simpler to regard Figure 2

representing the information received by a person reading Ulysses. On the first few pages the reader will be faced with many different words (types). Then after the more common words have occurred, the encounter of new words becomes less likely. Thus, the curve flattens out as the end of the book is approached.

Insert Figure 2 about here

In his study of the relationship between word variability and text length Carroll has been followed by a number of other scientists. In an earlier publication (Riegel and Riegel, 1965) we have reviewed the pertinent literature and selected the best fitting mathematical function for such a study (see Appendix A). In the present paper we will generalize these interpretations to the study of language development.

Generalizations and empirical support for the model: If a word count were available on all the books and materials which a person has read during his life span, we would expect a growth curve for his vocabulary quite similar to the one for the reader of James Joyce's Ulysses--only much longer. Moreover, if we maintain our assumption on the constant amount of daily reading, we could substitute the total number of pages read by the age of the reader or vice versa, leaving as an open question whether we regard the vocabulary as a function of the total amount of material read or of age.

Slicing off equal intervals on the ordinate of the curve, we may also use the enumeration of the different words as an indicator of a person's "reading age". At later ages, when the reader is far advanced in his "book of life" greater amounts of reading are required in order to produce equal amounts of reading growth. But as long as he continues to read, he will have a chance--even though a decreasing one--to encounter a word that has not occurred to him before. This word might be a new one, only recently introduced into the language, or it might be a rare word which requires an exceedingly large sample of the language for its occurrence.

Substantial evidence has been accumulated to support our propositions. During the first two years of life, scores on recognition vocabularies (McCarthy, 1954) show a

positively accelerated increase. Thereafter, the trend becomes negatively accelerated, but even during the adult and later years of life a high stability or a slight increase in scores has been noted in most of the previous studies (Riegel, 1965). Figure 3 includes a mathematical trend for a multiple choice vocabulary given to 500 Ss (Riegel, Riegel, and Meyer, 1966).

Insert Figure 3 about here

The evidence thus far reported is on recognition vocabularies and does not represent the words actively used by Ss. Unfortunately, much less is known about age differences in the active vocabulary of Ss. The present authors observed an increase in variability of responses to stimuli of an association test over an age span from 17 to over 75 years of life (Riegel and Riegel, 1964) and similar results have been reported by Riegel and Birren (1966) in their study of syllable associations of young and old Ss. Since all these investigations rely on cross-sectional comparisons, it remains possible that the increase in variability expresses an increase in vocabulary specializations, i.e., in inter-, rather than intra- individual variations.

This difficulty is resolved in word counts of diaries and journals written by a woman at a median age of 35 years and of letters written by the same person after the age of 68 years (see Figures 4A and 4B). In the analysis of these records, Madorah Smith (1955, 1957) observed an increase in word variability up to an age of about 75 years. She attributed the decline thereafter, to extraneous factors, particularly the declining health of the S.

Insert Figure 4 about here

The data of Figures 3 and 4 provide only indirect support for our interpretation. Ideally, complete counts of all the words read or written, heard or spoken during a person's life ought to be obtained, but such a study would be an exceedingly expensive if not an impossible endeavor. Fortunately, simplifications of the procedures are possible:

First, we may study time samples only. Second, we may stratify our material and restrict our analysis to specific strata, for instance, to nouns or verbs or adjectives. Indeed, we may go so far as to study only words beginning with a certain syllable or letter of the alphabet. Undoubtedly the type of restrictions will have its effects on the results, but by comparing different restrictions, generalizations may be drawn.

If we restrict our study in the indicated manner, we approximate quite closely the method of verbal fluency developed by Bousfield and Sedgewick (1944) in which Ss are asked to name as fast as possible words of a particular type, such as all the words beginning with the letter S or Q but to omit all others. Moreover, with this restriction we compress our procedures to such an extent that we may obtain our records during a single laboratory session.

Our comparison implies that Ss in the verbal fluency task are scanning through their repertoires in the same manner as readers would through the pages of a book in order to find particular words such as different S-words. To the person scanning a book for different S-words, the interspersed words are a nuisance and they become more so, the farther he has advanced in the text (because an increasingly greater number of words is interspersed between two new S-words). If the time intervals between the emission of adjacent words in the verbal fluency test are assumed to be proportional to those that elapse until a person scanning a book comes upon new words, and--moreover--to those that elapse until a regular reader encounters new words, we would have derived a method of simulating developmental processes in the laboratory. Let us apply this idea for the purpose of generating some experimental hypotheses.

Simulation of developmental processes: Previously, we cited some evidence that old persons have larger active as well as passive vocabularies than young Ss. Subsequently, their performance in verbal fluency tests ought to be superior. In order to test this hypothesis and--more generally--the idea of simulating aging processes with the verbal fluency test, we compared the accumulation of S- and Q-words in James Joyce's Ulysses with the production of such words by young and old Ss in ten-minute laboratory sessions.

In our study, 31 college students and 23 members of senior citizens' club were asked to write as many words as they could think of beginning with the letter S or Q, respectively. Ss marked the end of each 2-minute period on their papers. The number of responses given during consecutive periods was used in the analysis.

According to the results of Figure 5, our prediction that the larger vocabulary of old Ss should lead to a superior performance in the verbal fluency test was not confirmed. The total number of different words emitted during the 10-minute periods was found to be much smaller for the old than for the young Ss. Apparently, other factors than vocabulary size affect verbal output and prevent old Ss from making full and efficient use of their large vocabularies. Subsequently, we have to examine possible sources of interference and, generally, to explain the failure of our prediction.

Insert Figure 5 about here

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1. Thus far, we have exclusively dealt with the physical environment according to Lewin (1954) and la langue according to Saussure (1931). We have dealt only with the different words that occur in the surroundings of a S but not with the question whether indeed he registers and perceives these words or not. We have dealt with the words which he can possibly produce under optimal conditions but not with the limitations which a realistic situation imposes upon his performance. Quite different mechanisms representing psycho-biological changes rather than changes in physical or linguistic conditions will be involved in perceiving or producing words and sentences.

Figure 6 shows some characteristic data on age differences in the speed of silent reading and writing. Mature Ss read about ten times as fast as they write, but there is also a differential decline in writing speed beyond the age of about 50 years. The data of Figure 6 on silent reading speed have been collected by Pressey and Pressey (undated) for children between 7 and 14 years of age and by Hall and Robinson (1942) for Ss above 10 years of age. The data on writing speed have been obtained by Wills (1938) for children between 8 and 12 years of age and by Birren and Botwinick (1951) for Ss above 16 years of

age. Further information has been provided by Rader and O'Connor (1957, 1959). The decline in writing speed with age is one important factor that explains why old Ss produce markedly fewer words in the verbal fluency test than anticipated.

Insert Figure 6 about here

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2. A writer of a book will avoid undue repetition of words, but he is not rigidly restricted in his output. In the verbal fluency test, however, S is prevented from using the same response twice, and thus, he has to check any response he is intending to give against all the others previously emitted. This counter-checking of words causes interference and again differentially affects the performance of old Ss (Riegel and Birren, 1966). Moreover, the checking of words requires a good short-term retention span which, according to Figure 3, old Ss are lacking. The data of Figure 3 represents the Digit Span Subtest of the Wechsler Intelligence Scales for Children and Adults (Wechsler, 1949, 1955). The differential susceptibility to interference and the decline in retention span are other factors that explain why old Ss produce markedly fewer words in the verbal fluency test than anticipated.

3. The complexity of the sentences produced or comprehended is another important factor in the analysis of developmental differences in verbal behavior. Old Ss may differ from young in the syntactic or semantic structure which they are using or able to comprehend at a certain reading rate. The problem of linguistic structures seems far remote from the present interpretation, but, since basic components of such structures are classes and class relations, similarities become conceivable. After all, one major difficulty of the verbal fluency test consists in identifying members of a class and the performance is greatly facilitated if categories, such as S-words or words denoting particular groups of objects, pieces of furniture, animals, etc., are readily available to Ss.

In order to outline the role of linguistic structures for verbal performances, we have to analyze how classes are acquired, how their relations are recognized, and how transformations of these relations are performed. Although a detailed discussion of such

problems is beyond the scope of the present paper, we may show that age differences do indeed exist and are at variance with changes deduced from our model.

Figure 7 provides pertinent information on age differences in reading comprehension and sentence length. The data on the length of spoken sentences are taken from the review by McCarthy (1954, see table 5) and represent the average results of four studies. The data on the length of written sentences of children and adolescents are taken from the same source (see table 6) and represent averages of two studies. The data on the adult Ss have been made available through the courtesy of Dr. Madorah Smith (unpublished), and are based on large sets of letters written by three persons during spans of about 60 years. The results on "sentence comprehension" represents the scores on "paragraph meaning" of Pressey's Diagnostic Reading Test. The data on children's performances have been collected by Pressey and Pressey (undated), and those on adult Ss by Hall and Robinson (1942).

Insert Figure 7 about here

Limitations and further explications of the model: Since the results of the verbal fluency study seem to limit our statistical interpretation of language development, a reconsideration of the general purpose of the model seems appropriate. Primarily, the model will provide estimates of the upper limits of performance for individuals differing in age. Because of additional psychological factors, this upper limit will hardly ever be attained in real life situations. In analyzing these interfering factors, we proceeded to explain the observed differences between the data and the model.

Throughout our discussion, the individual has been regarded as an information handling system that changes over time; i.e., with the amount of information handled. The total amount of information provided, and particularly, the total number of different words given, increases with age. But because of intrinsic changes which are not primarily dependent upon environmental conditions, a person's speed of intake, for instance, his reading speed or his ability to comprehend verbal messages, changes as well and thus the relative amount of received (perceived) information is less than the amount of information

provided to him. As suggested in Figure 8, individuals may be regarded as functioning most efficiently during early adulthood.

Insert Figure 8 about here

For most types of performances, the received information has to be stored temporarily. Since there is a decline in immediate memory span, shown in Figure 3, further deficit will occur and the amount of information lastingly stored is less than the amount of information received. Some loss will also accrue when S calls upon the information stored. Because of slowness in expressing himself, such as in writing, and because of difficulties in constructing complex sentences, the amount of information produced is smaller than the amount of information stored. S's failure to formulate complex sentences is, of course, also dependent on his immediate memory span and will lead him to the use of short and redundant formulations (Birren, 1955).

Because of these losses in the transmission or handling of information, the overt performance does not match the total information provided. In order to evaluate this loss and the efficiency of the organism, we must first obtain an estimate of the information provided. It is here that the model and knowledge from literary statistics will be useful and will allow us to derive specific hypotheses. What are, for instance, the effects of a poor vs. a rich linguistic environment upon the performance of Ss differing in age? How does the environment of a person interact with his verbal abilities? What are the interdependencies of various abilities (perceptual, retentional, retrieval) at different developmental levels? Does the efficiency change with age, etc.?

In extension to our inquiry we may wish to study the determinants that bring about changes with age in perceptual, storage and retrieval functions. Most likely, these determinants are not exclusively related to the long-term developmental changes which we discussed, namely the overall increase in information provided, but may rather be sought among the changing biological capacities of the organism, i.e., among the non-linguistic, intrinsic conditions of the organism.

Certainly, most of the questions raised are not new. Similar notions are implied in de Saussure's (1931) distinction between la langue and la parole and in Kurt Lewin's (1954) distinction between a physical and psychological environment. Although Lewin has not given priority to the study of the physical environment, Barker and Wright (1949) as well as Brunswick (1949) have directed much attention to it. Barker and Wright regard the study of the contingencies in the physical environment rather than the study of particular psychological variables affecting the organism at any given instance as the most appropriate way of analyzing long-term changes of the growing organism. Similarly, linguistic contingencies have been analyzed but are still waiting for treatment by psychological ecologists and developmental psychologists. It is here where the proposed model may prove to be useful.

Finally, the present analysis may allow us to redefine the age variable in terms of changes in the response variability. Accordingly, we regard equal intervals on the ordinates of our figures (Figures 2 to 5) as representing units of "verbal age." Because of the negatively accelerated shape of the curves, corresponding intervals on the absissa increase toward the right end of the curves. In other words, "verbal age" progresses at a slower pace the larger the total amount of material already accumulated or already emitted.

The possibility of deriving a psychological scale of verbal age brings out an important implication of our discussion: In contrast to most other interpretations in developmental psychology we have remained faithful to an absolute age scale with interval properties instead of regressing to ordinal or partially ordered scales. Piaget's interpretations (see Flavell, 1963), for instance, with their periods of sensory-motor intelligence, preoperational intelligence, concrete and formal operations, constitute an ordinal age scale. Only the sequence of the periods is unambiguously determined, not the distances within or between them, and thus practical as well as theoretical difficulties arise when attempts are being made to map the boundaries of Piaget's periods or stages upon the chronological age scale. Since, in general, we have become firmly accustomed to the notion of developmental periods, however, we must explain how an interpretation of continuous changes would deal with these constructs.

First, our previous interpretations were concerned with the continuous growth of the vocabulary as derived from the notion of an accumulating amount of communication. However, we also mentioned the contrasting trend of a continued decline, notably in biological reactions as discussed by Bürger (1953). Both interpretations point to idealized limits. If we were to test any individual in a real life situation various interactions will take place and the observable performances will be like those shown in Figures 6 or 7. Consider, for instance, age changes in associative reaction time to verbal stimuli. Early in life the speed of reaction is high, but Ss are unable to discriminate and to respond quickly to verbal stimuli. Late in life the verbal habits are developed but the speed of reaction is lowered. Thus, only during the middle period and because of the optimal interaction between two continuous functions, is a maximum level of performance reached. Prior to that period, speed in performance grows; afterwards it declines.

Second, the linguistic environments impinging upon the growing individual differ in quality and type. Undoubtedly the language spoken to a baby differs markedly from that used among playmates, in elementary school, high school, in church, at the job, among friends, etc. Thus, we may need to describe language development as a series of shifts between subsystems of the language. Most of these subsystems (les paroles of de Saussure, 1931) are preselected for the growing individual in a more or less determined order and the confrontation with a new system is obligatory, as for instance, when a person enters one or another school, is drafted, retires, etc. Any new linguistic environment will shape the individual in a particular manner, and will make behavior periods sufficiently distinct even though it may share many features with the preceding and following ones. The problem raised is identical with the general question of cultural expectations that influence behavior periods like the periods of "nay-say", adolescence, post retirement, etc.

Third, and most important, the continuous growth, such as of the vocabulary, consists itself of small distinct steps, any one of which may lead to a burst of

information and thus provoke qualitative growth. Here, one is reminded of the implications which the acquisition of particularly mathematical and logical concepts, such as FUNCTION, INTEGRAL, as well as concepts like PROPERTY will have upon the behavior of an individual. More precisely, this sudden increase in the available operations on the basis of additions of single elements has been recently discussed by McLaughlin (1963).

This author attempts to explain the differences in the "logics" of children at the various developmental periods of Piaget, by differences in the immediate memory span. Even though the obtained developmental curves on the immediate memory span, such as for digits or words (see Figure 3 and Van De Moortel, 1965), are perfectly smooth, a child in a concrete testing situation recalls either two or three or four, but never 3.6 items. The increase in the number of items retained implies a marked increase in the number of conceptual, logical operations which the retainer can perform. A person who can retain two items at a time is able to perform simple categorizations according to the presence or absence of certain attributes or according to membership or non-membership in a group. If four items can be retained, items can be simultaneously categorized in two dimensions, and thus, the possibilities of analogical inferences, and syllogisms and many other operations are open to the child.

McLaughlin's interpretation is important because it reduces the typology of a stage model to an interpretation of development as a continuous process. Developmental periods in the logical operations of children are reflections of their memory capacities which attain only discrete values in concrete testing situations. Even though average values may be computed and will yield perfectly smooth developmental curves of immediate memory span, it is more reasonable to separate discrete developmental levels corresponding to ages at which children are likely to retain two, three, four, five, items, etc., respectively.

The significance of McLaughlin's argument is further revealed because it holds equally well in the area of grammar learning. Grammar, and generative grammar in

particular, allows to construct (project) the infinite set of linguistic expressions on the basis of finite set of elements, classes, and class-relations. In our present discussion we have been primarily concerned with the acquisiton of elements (words), which are the prerequisite for the acquisition of classes and class-relations (Riegel and Riegel, 1963). As soon as classes and class relations are acquired, a burst of generative possibilities occurs, and, the child will be able to produce many new formulations which, formerly, he could not generate without matching input information. Dependent on the number of grammatical classes and class-relations which a child has incorporated into his language, linguists may be inclined to separate distinct periods in the development of grammar. Again, the underlying learning process is a continuous one but the products to be utilized for grammatical performances, the classes and class-relations, are qualitatively distinct and in turn may create the impression of qualitatively distinct periods in the grammatical development.

Summary

In our outline, we have emphasized the role of language as an objective and quantifiable system with which an individual is confronted throughout his life. The sum total of verbal input and output increases with age. As the total amount of verbal input or output increases, the total number of different words perceived or produced increases as well. The increase in the number of different words with the total number of words has been empirically tested. The increase in vocabulary, for instance, is at first positively accelerated (1 to 2 years), and becomes negatively accelerated or zero during adulthood and later years of life. Also, the active verbal repertoire, as tested in word counts of letters, journals, or responses to association tests, increases in a similar manner. Thus, older persons have available a larger passive, as well as active vocabulary than young Ss.

The increase in the number of different words with the total number of words (or time) has been studied by different scientists and theoretical models have been proposed. The equation derived by Bousfield and Sedgewick (1944) predicts best changes of both the active and the passive repertoires. For this equation it is assumed that the increase in different words is proportional to the number of different words not yet used.

The analysis of complete, cumulative records is very laborious. Instead one might simply ask Ss to write or say all the different words that occur to them during consecutive time intervals. Thus, by excluding all the repetitions of words, one reduces extensive literary records to the tabulations of short laboratory sessions. The verbal fluency test represents such a method and the equation of Bousfield and Sedgewick has been originally derived for the analysis of such data.

Since older Ss were found to have larger passive as well as active vocabularies we should expect that their performances on the verbal fluency tests would be superior to young Ss. This prediction could not be confirmed. The following factors might explain our failure: In comparison to literary performance, the verbal fluency test is a speed task, and time limitations are known to effect differentially the performance of old Ss. In the verbal fluency test Ss have to avoid repetitions of words. This causes interference and might differentially effect old Ss, particularly, since comparisons of any intended response with those previously emitted require a good immediate memory span which old Ss are known to be lacking.

Throughout our discussion, the human organism has been regarded as a system that changes with the total amount of input it receives and/or the output it produces. Thus, our interpretations have been closely similar to the description of physical systems that change under the influence of external conditions. However, the analysis of our verbal fluency data has also revealed that a study of the physical, linguistic contingencies will provide an upper limit of performance only. Of greater importance for many psychologists might be the analysis of those factors that prevent the individual from making the most efficient use of the information provided. Deficiencies in perceptual, storage, and

retrieval functions characterize such limiting factors. An explanation for the developmental changes of theses functions may need to be based on other than the physical and linguistic conditions in the environment of the individual, and may need to be reduced to developmental changes in intrinsic, biological components.

APPENDIX

Mathematical models of changes in word variability with text length: Carroll's (1938) model on the relationship between word variability and text length is based on the harmonic series law of the word frequency distribution which is also known as Zipf's law. Zipf (1949) plotted the logarithms of the frequencies against the logarithms of the word rank. When a rank of 1 is assigned to the most frequently used word the relation is found to be linear with a slope of -1.

Although the rank frequency relation has been empirically confirmed for the language of many different groups of Ss as well as for data from different other areas in psychology, sociology and economics, the method, has been equally often criticized. Since Herdan (1960) has shown that the negative slope follows from the fact that ranks are selected as one of the variables and frequencies as the other, the only remaining, significant aspect of the law consists in the type, namely the linear relationship between the variables.

Herdan's criticism weakens Carroll's analysis which led to the following equation:

$$D = \frac{N}{K} (.423 + K - \ln N + \ln K)$$

where D is the number of different words in a sample of N words and K is an empirically determined constant. Since Carroll's derivation is not based on differential equations, it is difficult to compare his method with some of the others.

Chotlos (1944) applied Carroll's formula to the analysis of children's writings and emphasized that the condition for the derivation of the formula, namely a slope of -1, is better met when the first 20 ranks are omitted. But even then the fit between the empirical and the predicted values remain unsatisfactory and thus Chotlos retreated to an empirical method of curve-fitting using two free parameters. Plotting log D against log N, a reasonably linear relationship was detected. By the method of least squares the constants a and b of the following equation were computed:

$$\log D = a \log N + \log b$$

Herdan (1960) has provided a clear rationale for this equation by relating it to functions which had been previously applied to studies of differential growth in biology,

sociology, and economics. (Thus, time measures instead of text length (N) were used in the derivation of the equation.) For the derivation of the growth function, the following assumptions are regarded as essential by Herdan: "The rate of growth of a system growing equally in all its parts is at any moment proportional to the size of the system; . . .the rate of growth slows down with increasing age, i.e. size of the system; . . . and . . . is affected by the external environment. Whereas the two latter considerations affect all parts of the system equally, so that we may suppose that the growth-rate of any particular organ is proportional simultaneously (a) to a specific constant characteristic of the organ in question, (b) to the size of the organ at any instant, and (c) to a general factor dependent upon age and environment which is the same for all parts of the body." (Herdan, 1960, p. 27).

Similar, for the study of linguistic material, Herdan says: "We may suppose that the growth rate of the vocabulary is proportional simultaneously (a) to a specific constant characteristic of the accumulation of vocabulary with increasing text length, (b) to the magnitude of vocabulary that has already accumulated, and (c) to the particular conditions of writing as due to style, content, etc. The same applies to text length, as a characteristic of the whole system." (Herdan, 1960, p. 27).

Herdan derives two differential equations in which α and β are specific constants for text length and vocabulary, respectively, and G for the "environmental" conditions of growth as affected by style and content of the text.

$$\frac{dD}{dt} = \alpha DG$$

$$\frac{dN}{dt} = \beta NG$$

Eliminating G and integrating, Chotlos' (1944) above mentioned equation of the vocabulary growth has been derived.

In Herdan's differential equations the increase in the number of different words is proportional to the number of different words that have already occurred, (D). The same reasoning is implied in the equation on the total number of words, (N). These assumptions seem unrealistic, however, for psycholinguistic as well as biological, economical and sociological phenomena because they imply positively accelerated growth which is observed

under rare conditions only. More often the development is balanced by other factors. In the study of population growth, for instance, an unlimited, positively accelerated growth is counteracted by lack of nutrition, which converts the curve into a negatively accelerated function, and leads to the approximation of an equilibrium. Similar, in studies of language acquisition a positively accelerated growth of the vocabulary has been observed for the first two years of life only. At an age of 2 the curve changes into a negatively accelerated trend. Possible reasons for these changes might be S's limitation in memory capacity or lack of sufficient environmental stimulation.

By combining the two differential equations and by eliminating the common factor, G, Herdan succeeds in obtaining a negatively accelerated function. However, the results of figure 4A and 4B show a relatively poor fit between his predictions and the empirical data. Herdan's formula underestimates slightly the word variability in the first part of the figure, and overestimates it to a considerable degree in the second part. Thus, his predictions seem unsatisfactory for the present material. In our search for another model we selected the method proposed for the analysis of verbal fluency data by Bousfield and Sedgewick(1944).

Bousfield and Sedgewick have based their differential equation on the assumption that the increase in D with time (t) is proportional to the number of different words that have not yet occurred to S. Thus, if L is the total number of different words and D is the number of different words that have occurred up to a certain point, their differential equation reads as follows:

$$dD/dt = m(L-D)$$

$$D = L(1-e^{-mt})$$

Bousfield and Sedgewick's function is negatively accelerated and, with the exception of some slight deviations in the early parts, predicts very well the empirical data of figures 4A and 4B. It is not feasible, however, to relate N_∞ to t as Herdan has suggested for his own equation, since N cannot possibly approach N in time intervals that are of interest here. If we assume instead that N is linearily related to t, we obtain a further equation which has been originally proposed by Yule (1944).

Yule's analysis is based on the Poisson law of rare events and has been summarized by Herdan as follows: "According to the law of rare events, the probability of one of L words not occurring in a proportion Np of a text of length N is $e^{-Np/L}$, and consequently the probability of its occurrence is $1-e^{-Np/L}$. The probable number of words of the group in a text of length N is then . . ." (Herdan, 1960, p. 76):

$$D = L(1-e^{-Np/L})$$

Whereas Bousfield and Sedgewick's equation expresses a function between D and time, Yule's equation relates D to the length of a text, N. If we assume that $t = kN$, the rate factor, m, in Bousfield and Sedgewick's equation becomes equal to p/L in Yule's equation. Both formulas include two unknown components. Bousfield and Sedgewick propose a short-cut method to estimate L and m, whereas for Yule, L and p are objectively determined. L represents the total number of different words of a subsystem, such as all the different words beginning with the letter S; p represents the proportion of all these words in the total text N, i.e. including repetitions. Since it is impossible in most cases to derive these components in the manner described by Yule, Bousfield and Sedgewick's method seems more generally suited for the present purpose.

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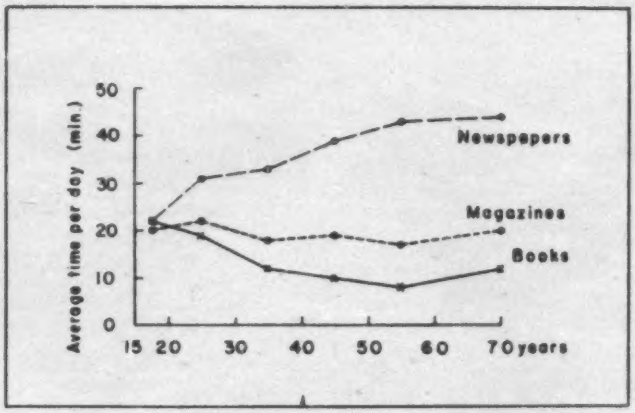

FIG. 1. Amount of time spent on daily reading by different age groups (Link and Hopf 1946).

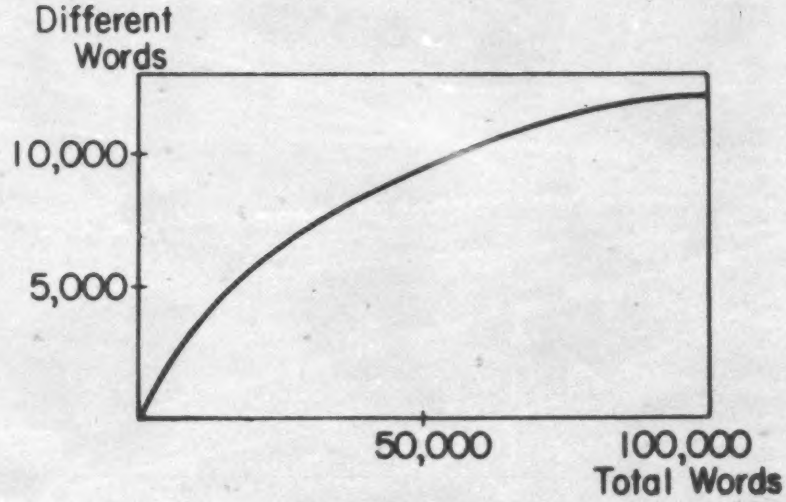

FIG. 2. Predicted number of different words as a function of total number of words in James Joyce's Ulysses (Carroll 1938).

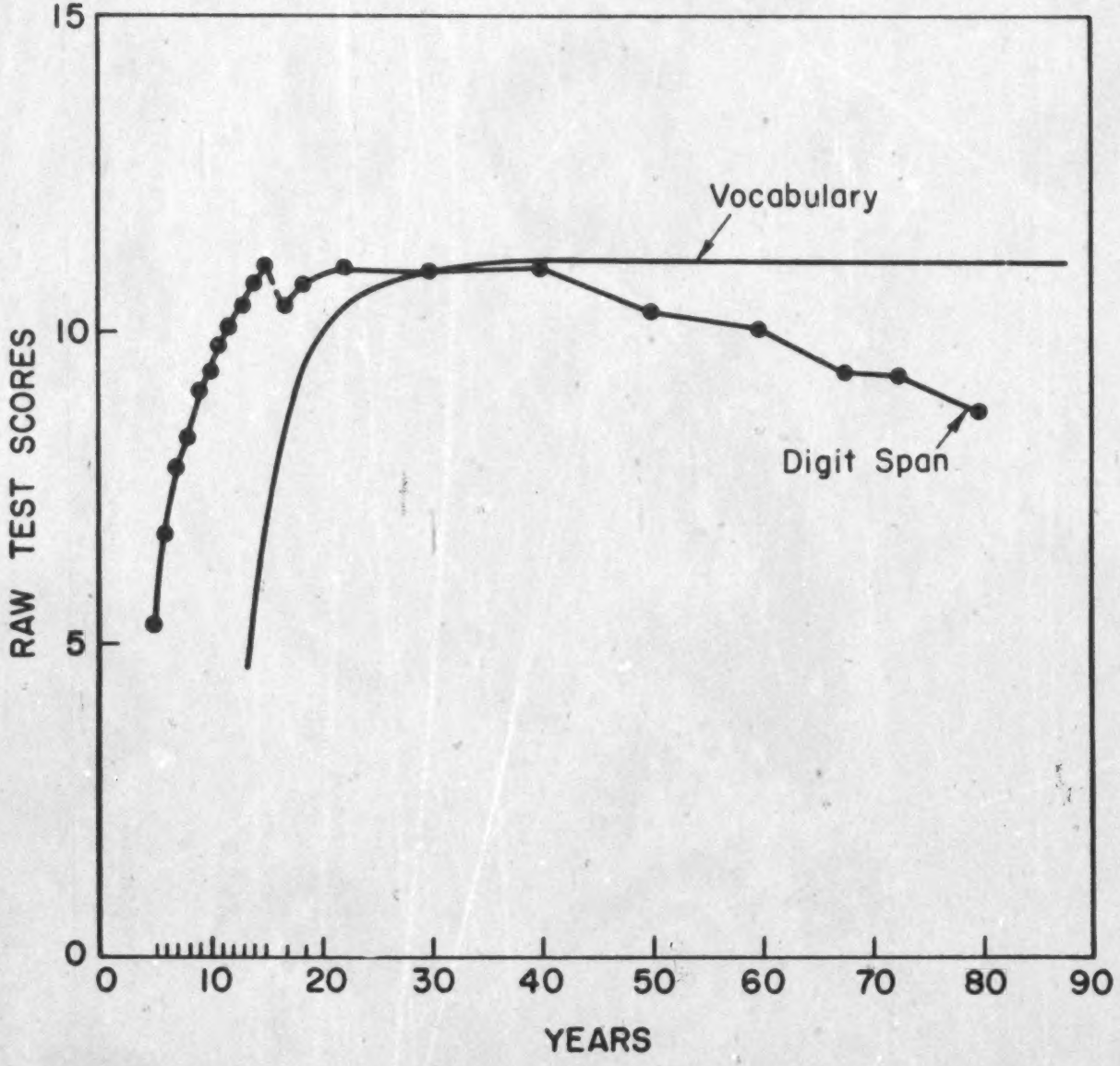

FIG. 3. Mean scores on a vocabulary and digit span test for different age groups (Riegel, unpublished data; Wechsler 1949; Wechsler 1955).

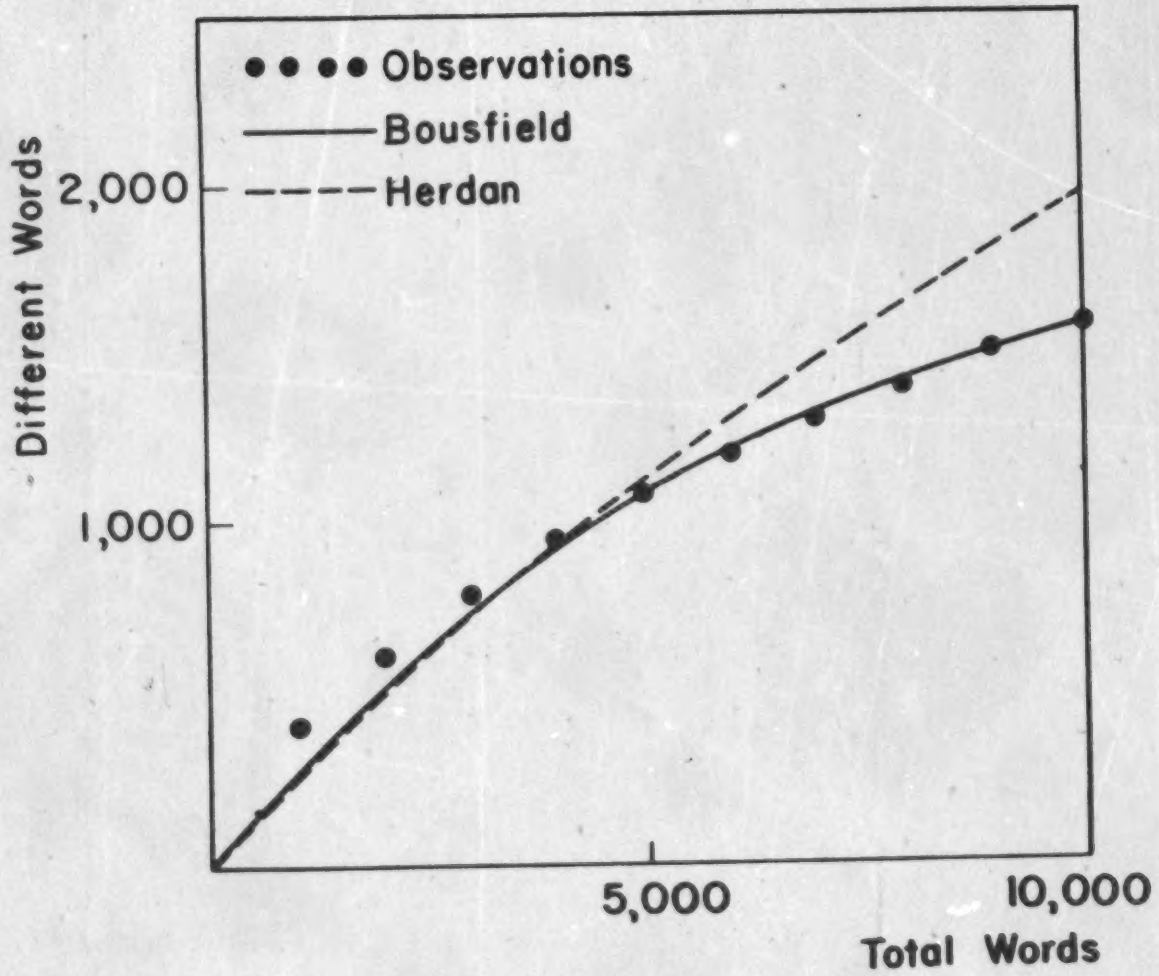

FIG. 4A. Accumulated record of different words written by a 35-year old S plotted against text length (After Smith 1957ab).

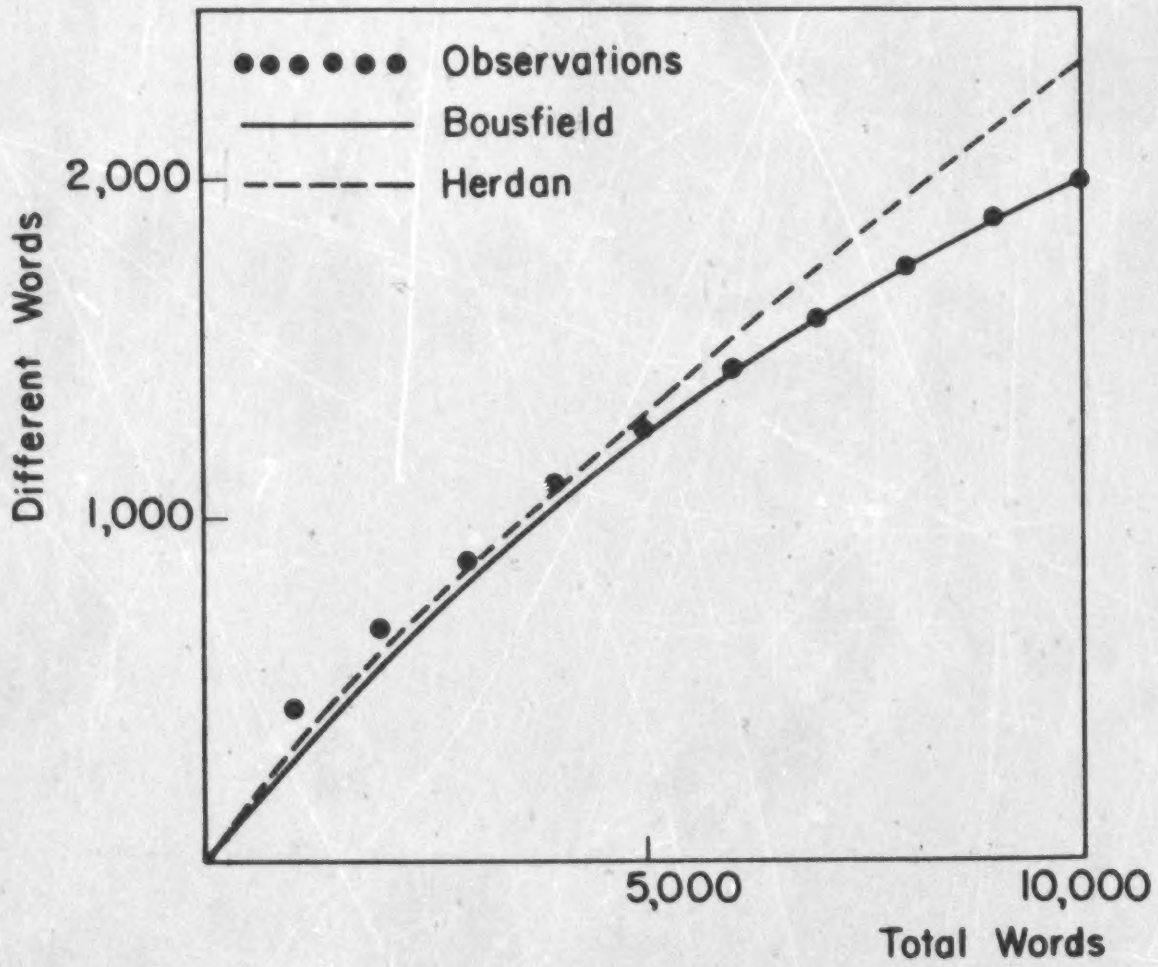

FIG. 4B. Accumulated record of different words written by a S after her 68th year of life plotted against text length (After Smith 1957ab).

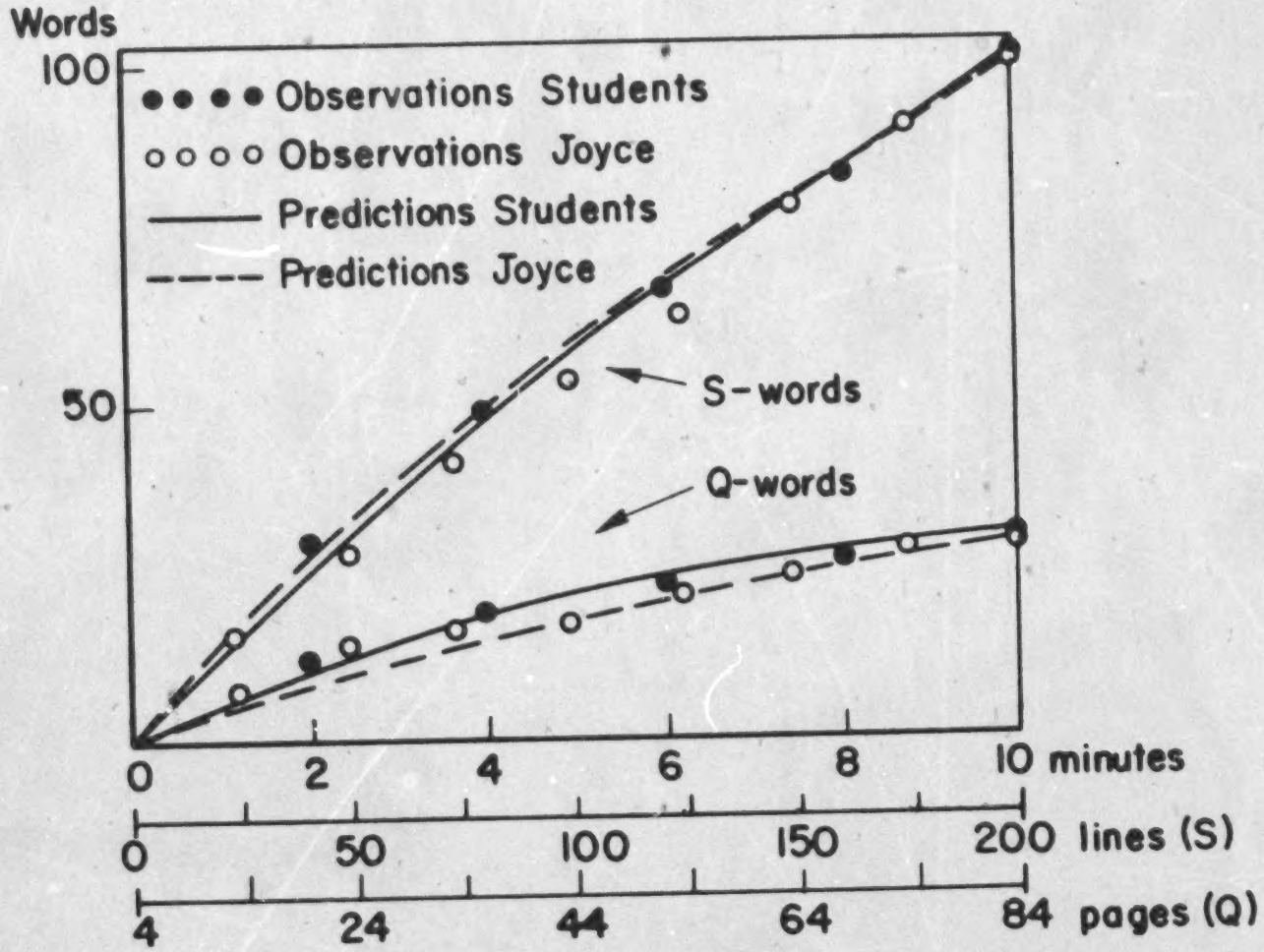

FIG. 5A. Number of different Q and S-words written by students and by James Joyce plotted against time or text length.

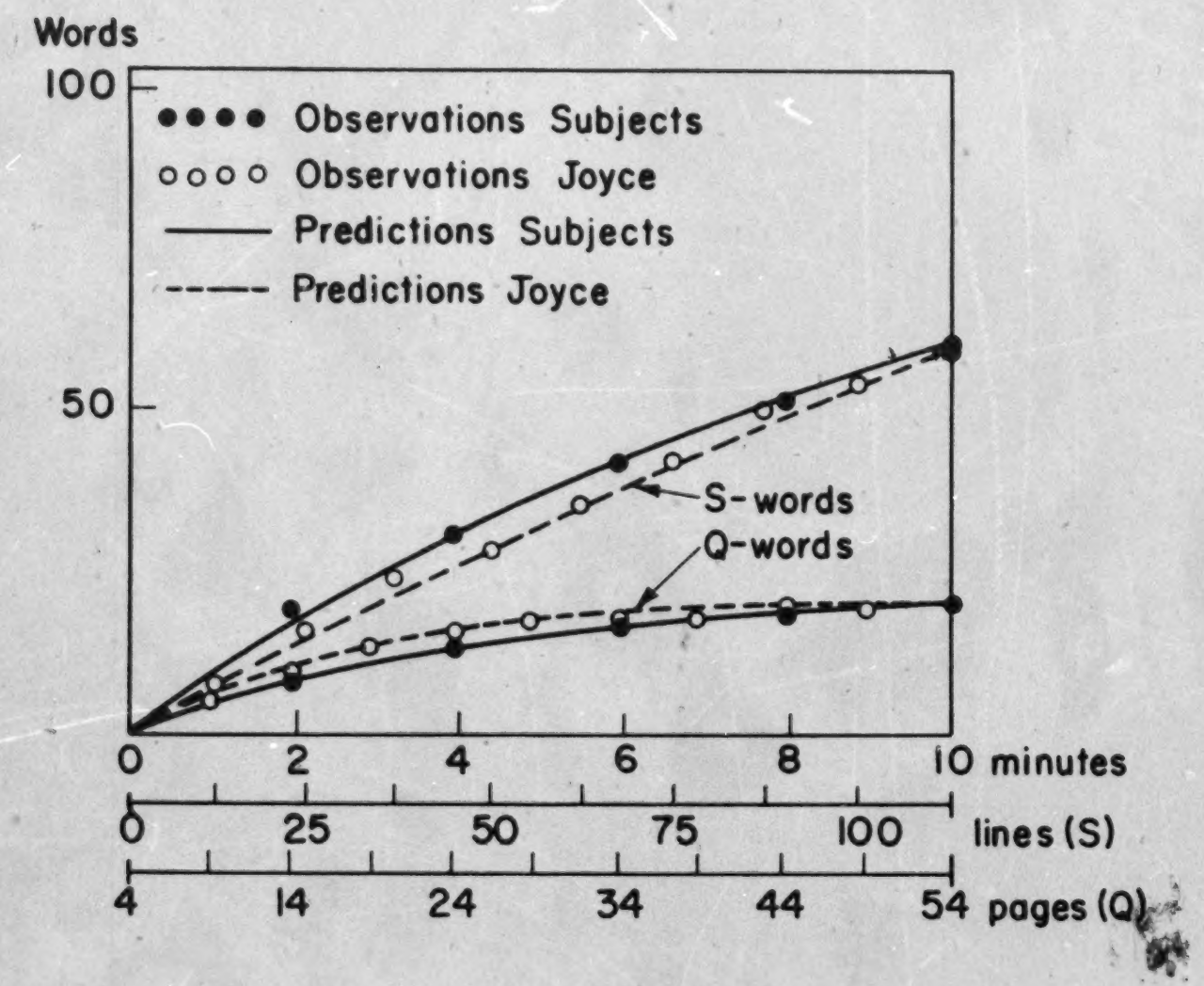

FIG. 5B. Number of different Q and S-words written by old Ss and by James Joyce plotted against time or text length.

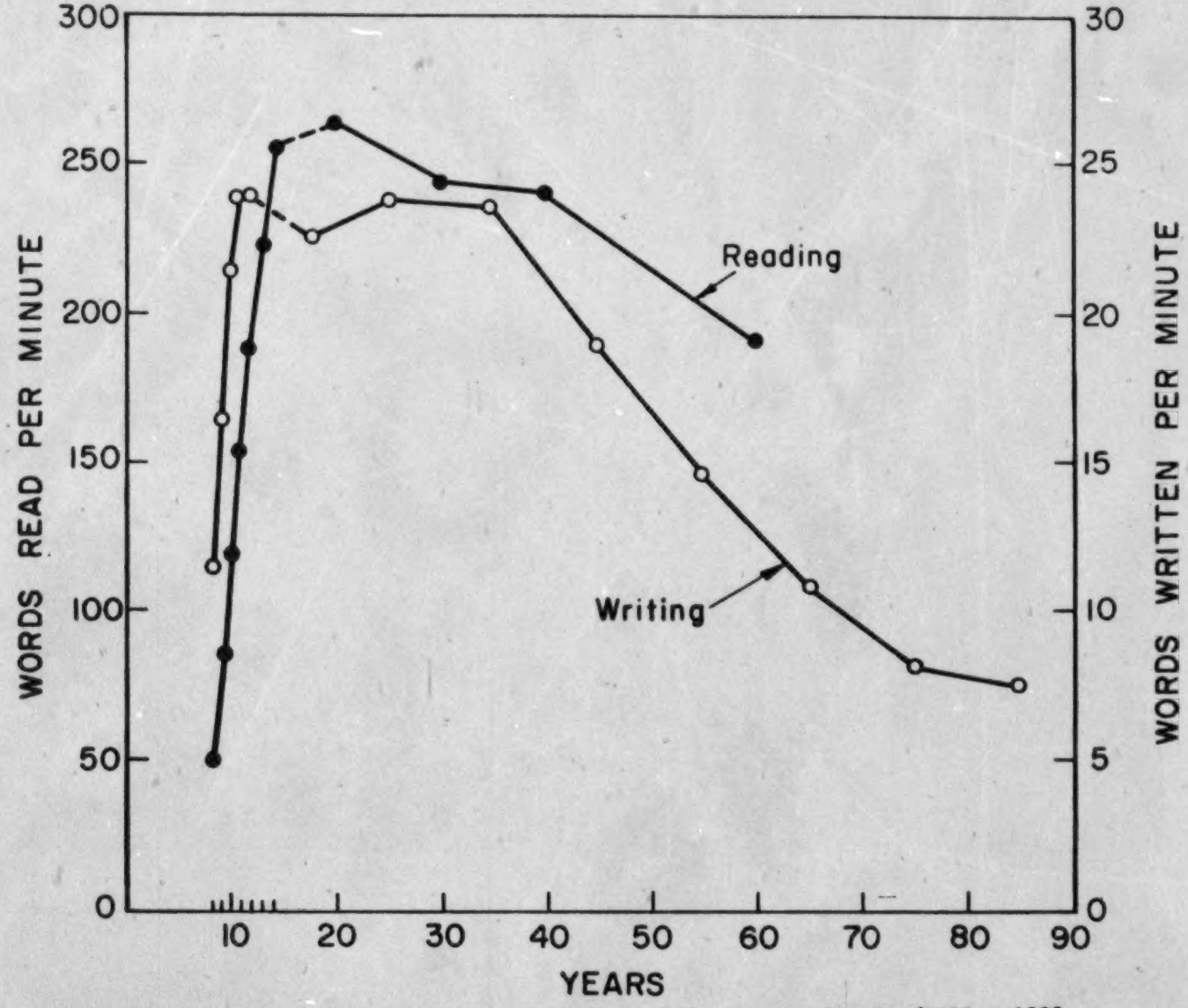

FIG. 6. Speed of writing and reading at different age levels (Wills, 1938; Birren and Botwinick, 1951; Pressey and Pressey, undated; Hall and Robinson, 1942).

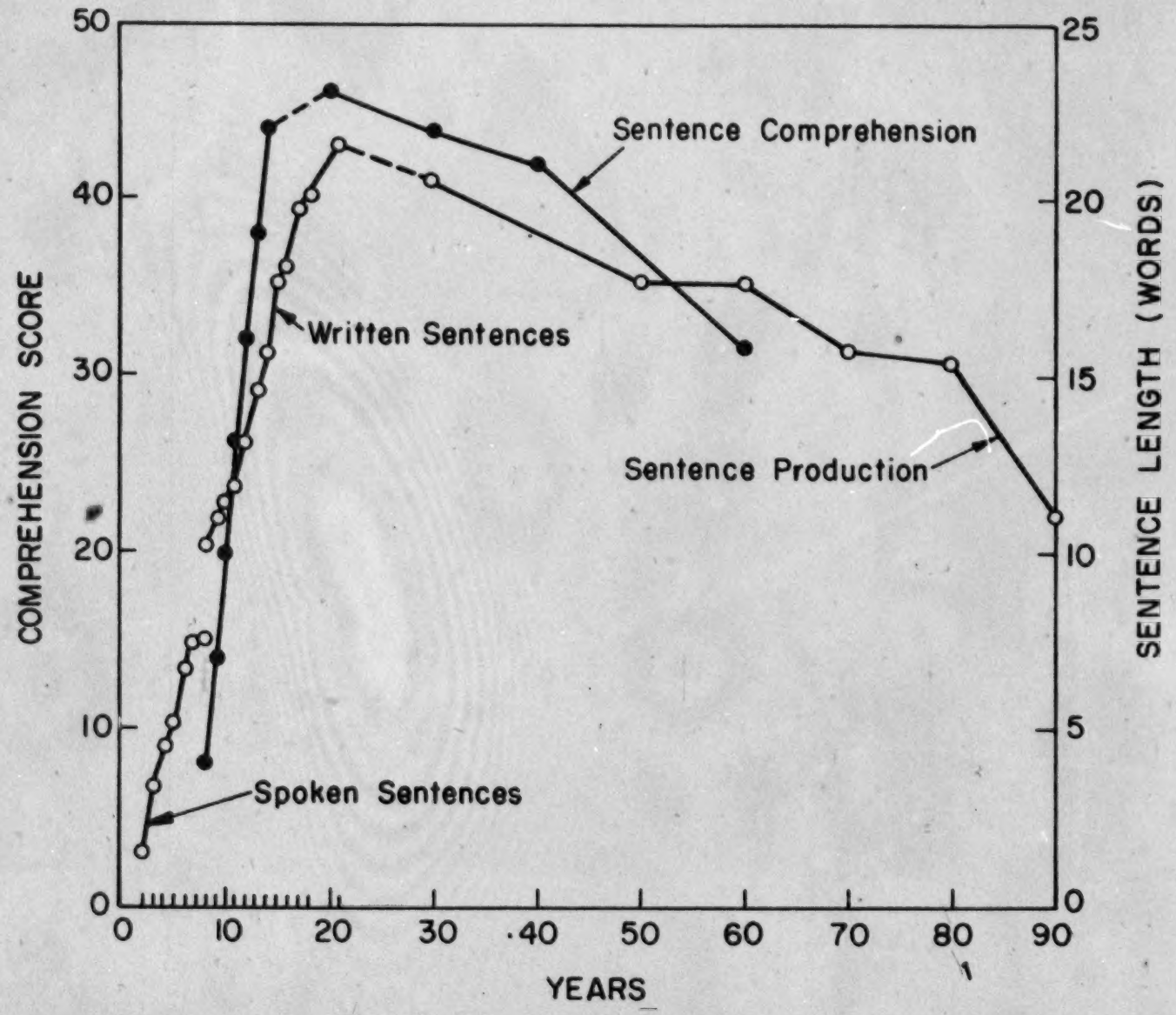

FIG. 7. Sentence comprehension and production at different age levels (Pressey and Pressey, undated; Hall and Robinson, 1942; McCarthy, 1954).

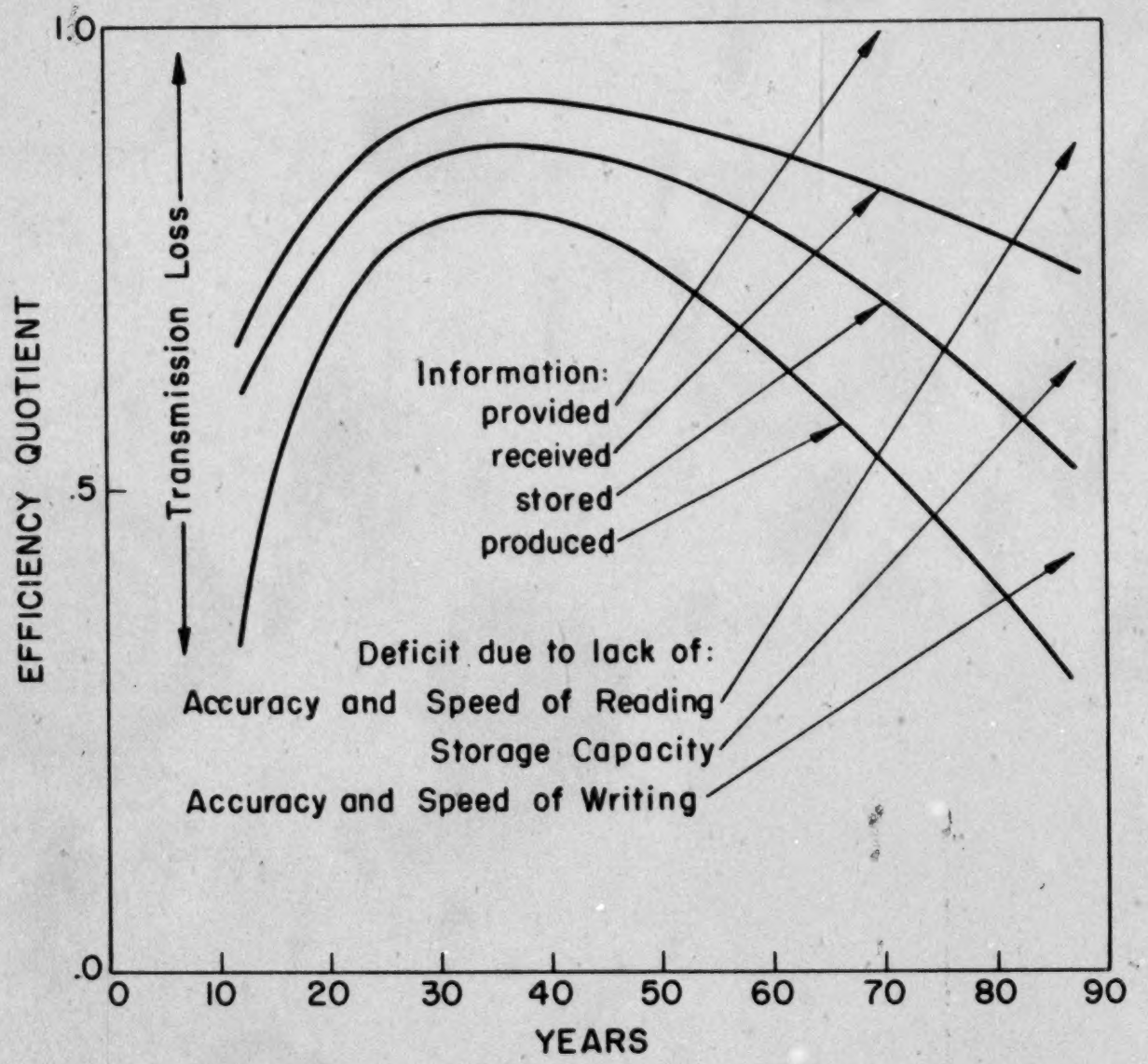

FIG. 8. Hypothetical representation of transmission losses at different age levels.